

PROCEEDINGS
2019 AUSTRALIAN GEOMECHANICS SOCIETY
VICTORIAN SYMPOSIUM

**Geotechnical characterisation –
managing design and construction risk**

Wednesday, 30 October 2019, 8:00am – 7:00pm
Rydges Hotel, 186 Exhibition Street, Melbourne



AUSTRALIAN GEOMECHANICS SOCIETY
VICTORIA CHAPTER



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PREFACE

The Victorian chapter of the Australian Geomechanics Society invited academics and practitioners in the field of geotechnical and ground engineering to attend the 2019 Australian Geomechanics Society Victorian Symposium held on 30 October 2019.

In recent years Victoria has seen significant growth in the construction industry. Investment in both public infrastructure and commercial real estate is growing, and as our cities and infrastructure grow, so too does the need to develop parcels of land with challenging ground conditions. Economical and safe geotechnical design requires efficient and well thought through ground investigation and characterisation to identify and manage ground risks and opportunities.

The 2019 Australian Geomechanics Society Victorian Symposium presents an overview of current state-of-the-art practices, innovation, new research results and case studies relating to geotechnical characterisation with an emphasis on its implications for addressing and managing design and construction risk. The 2019 Symposium brought together professional engineers, researchers, specialist contractors, regulators, educators and students to share and discuss their experiences on the topic of ground characterisation.

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Estimation of Seismic Load for Design of Low Consequence Category Tailings Dams

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ABSTRACT

Seismic design of embankment dams often requires assessment of the earthquake induced ground and dam movements. There are multiple cases where earthquakes have resulted in sliding and lateral spreading of embankments, crest settlement, and in some instances liquefaction and embankment failure. Hence, evaluation of the effects of earthquakes on embankment dams is of paramount importance for the design. A site-specific seismic hazard study is generally the first step to estimate the potential earthquake loads and the results are often presented in the form of site response spectra, earthquake time histories, and/or plots of peak ground acceleration (PGA) for "rock outcrop". The PGA and earthquake motions which are used in liquefaction, stability and deformation analyses of embankment dams are to be further processed to develop those within or at the top of the structure. Empirical ratios or deconvolution of the input motion are used for this purpose. There are significant uncertainties involved with the former approach whilst for the deconvolution process earthquake time histories are vital, which are not readily available, at least during the early stages of a project. In this study, a series of one-dimensional response analyses of several Australian dam sites were carried out using SHAKE software (GeoMotions, 2012) to investigate the effects of material parameters (i.e. shear wave velocity) and embankment height on amplification ratios. The results are presented and compared in this paper. A general framework is also provided to estimate the PGA for the embankment analyses for low to significant consequence category tailings dams in Australia where the earthquake design load or a site-specific seismic hazard analysis is not available.

Keywords: PGA, earthquake, response analysis, embankment dams, rock outcrop, SHAKE.

1 INTRODUCTION

According to the Tailings Dams Risk of dangerous occurrences (ICOLD, UNEP and USCOLD, 2001) 14% of tailings dams failures had occurred due to seismic liquefaction. Other earthquake hazards include vibration induced deformation, ground or fault displacement within the embankment foundation or impoundment area, and landslides into the impoundment. Ground shaking can result in liquefaction of the foundation and/or embankment materials (if susceptible to liquefaction) or induce deformation, settlement and cracking in the embankment. Ground or fault movement in the dam foundation creates structural distortion of the retaining structure or if present in the bottom of the impoundment potential loss of storage, reservoir seiches, overtopping and possible rockfall or landslide may eventuate. In the case of seismic design of earth and rockfill dams, an accompanying site-specific Seismic Hazard Analysis (SHA) is usually required to establish an appropriate level of earthquake design loads.

This paper presents a general framework that can be potentially applied to sites in Australia, where a site-specific SHA is not available. The common practice is to determine the PGA from the earthquake hazard maps provided in the Australian Standards (AS1170.4-2007) or the National Seismic Hazard Assessment (NSHA 2018) based on the site location. The accelerations provided in these maps correspond to the Rock Outcrop Motions, as schematically shown in Figure 1. The motions at the base and crest of the soil/tailings deposit or embankment profile are referred to as Bedrock and Surface Motions, respectively. When a liquefaction assessment is carried

out for a tailings dam, the acceleration profile within tailings profile and/or embankment dam will be required.

The current study involves a series of seismic response analyses to model the wave propagation in soil/tailings profiles using SHAKE software (GeoMotions, 2012) with the main focus being tailings dams. A combination of various material properties, eight (8) different earthquake time histories, three (3) different embankment heights and two (2) rock outcrop shear wave velocities, for four (4) sites around Australia were investigated. SHA including uniform hazard spectra (UHS) and acceleration time histories were available for these sites.

2 BACKGROUND

As indicated in ANCOLD guidelines (2019) the amplification of seismic waves is based on their

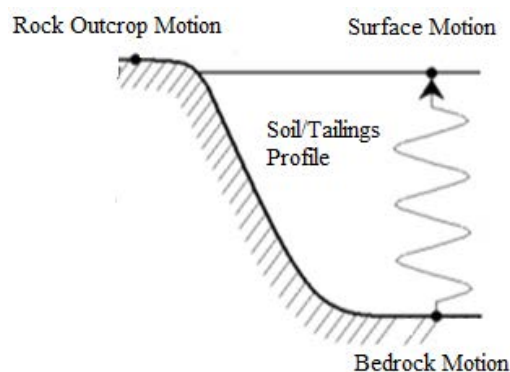


Figure 1: Seismic Waves vertical amplification through softer stiffness material.

amplitude and the material through which they travel. Amplification tends to occur on a vertical plane when waves travel from a higher stiffness material into a softer stiffness medium as shown in Figure 1. This figure shows the representation of rock outcrop motion and its amplification to the top of the soil column. The 2001 liquefaction workshop (Youd et al, 2001) recommended that the peak horizontal ground acceleration (PGA) in a simplified liquefaction analysis procedure to be estimated from one of the following 3 methods, in the order of preference:

- i. Based on attenuation relationships
- ii. Site response analysis (ie using SHAKE)
- iii. Amplification ratios (least desirable)

Method (i) is based on empirical attenuation models between PGA and the earthquake magnitude and distance from the seismic energy source, and local site conditions. These relationships are essentially the same as those used in a site-specific SHA and mainly developed for sites on bedrock or stiff soils. The models for sites on soft or even stiff soils are limited and not considered adequate. Hence, accelerations from site specific SHA are generally reported for rock outcrop motions which need to be deconvoluted in a seismic response analysis to obtain the acceleration profile within and at the top of the superficial soil deposit and/or dam fill materials using method (ii). Method (iii) uses amplification ratios which have been developed by previous studies (Idriss, 1991 and Seed et al, 1994). Figure 2 shows the variation of the PGA amplification ratio with the rock outcrop acceleration at the soft soil sites studied by Idriss (1991). Nonetheless, the amplification ratio is a function of natural frequency (i.e. depth and shear wave velocity) of the superficial deposit and/or dam fill, relative to the frequency contents and magnitude of the earthquake and can range from values of significantly below 1 to well above 1.

Method (ii) has been adopted to study four different tailings dam sites with different design earthquakes in Australia. These dams were raised using the upstream construction method in which the embankment raises were founded on the previously deposited tailings (i.e. embankment axis is shifted upstream when is raised). Depending on the nature of the deposited tailings, their density, segregation behaviour and material characteristics, the propagation of the earthquake motion will differ, as discussed in the following sections.

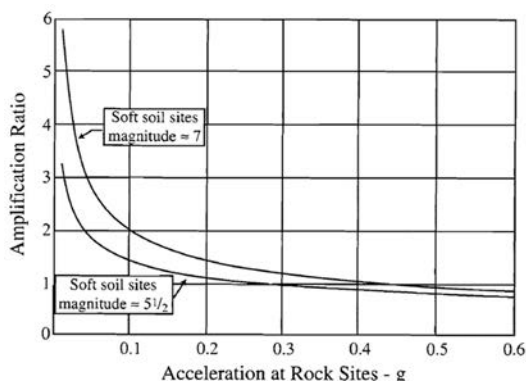


Figure 2: Variations of PGA Amplification Ratio with Rock-Outcrop Accelerations at Soft Soil Sites (after Idriss, 1991).

3 METHODOLOGY

3.1 General

SHAKE software (2012) was used to carry out a series of one-dimensional seismic response analyses including various tailings profiles overlying a bedrock foundation and seismically loaded employing different earthquake time histories. The effect of change in material parameters and profile (column) heights were investigated.

The analyses were carried out for 3 embankment/tailings profile heights of 10m, 20m and 30m (refer Figure 1).

3.2 Project Sites

The analyses were developed for 4 project sites in Australia. Sites 1 and 2 are located in South Australia whilst project sites 3 and 4 are located in New South Wales. All these sites had Site specific SHA including earthquake time histories as well as UHS.

The Australian continental mass is located within the Indo Australian Plate. No major fault line crosses the Australian territory. Nonetheless the plate collides in the north with the Eurasian plate and the Pacific Plate to the east. The major seismic events witnessed in Australia are a consequence of pent-up stresses caused by intercontinental plate interaction. According to the NSHA map, the regions with higher seismicity are located in the south-western areas of Western Australia, the Flinders Ranges in South Australia, and across a wide area from Tasmania to northern New South Wales.

3.3 Consequence Category of Dams

In accordance with ANCOLD guidelines (2012) the consequence categories for a dam failure is assessed on the likelihood of failure and the potential consequence in terms of:

- Risk to human life, either Population at Risk (PAR) or Potential Loss of Life (PLL)
- Severity of damage including loss to property, dam operations, the environment, credibility or financial viability, political impact, and health social and economic disruption.

The focus of this investigation is design of low and significant consequence category tailings dams in which the consequence of failure would be limited i.e.:

- PAR is expected to be less than 1; and
- Severity of damage is expected to be medium or lower.

Recommendations from this study may not be applicable to dams with high or extreme failure consequence categories.

4 SELECTION OF EARTHQUAKE TIME HISTORIES

Generally, for the seismic response and deformation analysis and design of dams, two levels of earthquake loading need to be considered as recommended by ANCOLD (2019):

- Operating Basis Earthquake (OBE): OBE is for the purpose of evaluating the dam's serviceability. This earthquake loading has a shorter return period and may occur during the life of the dam. Design of dams on this basis allows only minor and easily repairable damages to occur. The dam and associated structures must remain functional after the occurrence of earthquake shaking not exceeding the OBE.

- Safety Evaluation Earthquake (SEE): SEE is the maximum level of ground motion for which dam design is to be undertaken and the minimum seismic load for which the impounding capacity of the dam should be maintained.

For this study, only earthquake time histories computed for the rock outcrop motions corresponding to the SEE were considered. Sites 2 and 3 were studied with one earthquake time history each whilst for Sites 1 and 4 three earthquake time histories were adopted. The characteristics of the adopted earthquakes are summarised in Table 1.

Table 1: Adopted Earthquakes Characteristics

Earthquake	Magnitude	PGA
H – Cape Mendocino	7.1	0.72
H – Loma Prieta	6.9	0.32
H - Tabas	7.4	0.3
J – San Fernando	6.6	0.21
MA - Northridge	6.7	0.15
C – San Francisco	5.3	0.27
C – Sierra Madre	5.6	0.18
C – Whittier Narrows	6	0.22

5 MATERIAL PARAMETERS

5.1 Small Strain Shear Modulus

The initial (maximum) Shear Modulus, G_{max} , is a measure of the stiffness of the material at very small strains, whilst the Modulus Reduction function describes how the stiffness degrades at larger strains. G_{max} for tailings was determined based on two shear wave velocities of 200 m/s and 300 m/s, a range typically expected for tailings. The shear wave velocity or shear modulus of tailings is required to analyse the shear wave propagation in the profile. The adopted shear wave velocities together with the calculated first natural frequencies/periods for various tailings column heights are presented in Table 2.

Table 2: Shear Wave Velocities and calculated Natural Frequencies/Periods of Tailings Profiles

Shear Wave Velocity (m/s ²)	Profile Height (m)	Frequency (Hz)	Period (s)
200	10	5.00	0.20
	20	2.50	0.40
	30	1.67	0.60
300	10	7.50	0.13
	20	3.75	0.27
	30	2.50	0.40

The adopted shear wave velocity for the foundation rock was set to 750 m/s.

5.2 Modulus Reduction Curves

The strain softening behaviour of a soil during cyclic loading is often represented by a reducing shearing modulus as a function of cyclic shear strain, which is represented by modulus reduction or degradation curves/functions. These curves are used in an equivalent linear analyses to describe a decreasing stiffness at larger strains.

The modulus reduction functions for tailings were obtained from the database included in the SHAKE database (2012), as presented in Figure 3. Type A curve is from Vucetic & Dobry (1991), recommended for fine grained materials with a plasticity index (PI) of 0 and type B is from Seed & Idriss (1970) given for SAND. As can be seen, these curves are not significantly different.

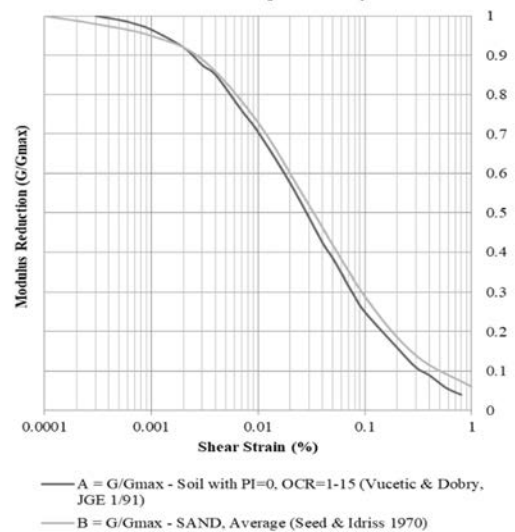


Figure 3: Modulus Degradation Curves for Tailings Types A and B (SHAKE 2003)

5.3 Damping

Damping describes the hysteretic dissipation of energy within a material when subjected to cyclic loading. Similar to modulus degradation, the damping curves for tailings are from the SHAKE database, as shown in Figure 4. An initial small strain damping ratio 0.5% was adopted for the tailings as the hysteretic damping shown in Figure 4 could not completely damp the high frequency components of the dynamic inputs.

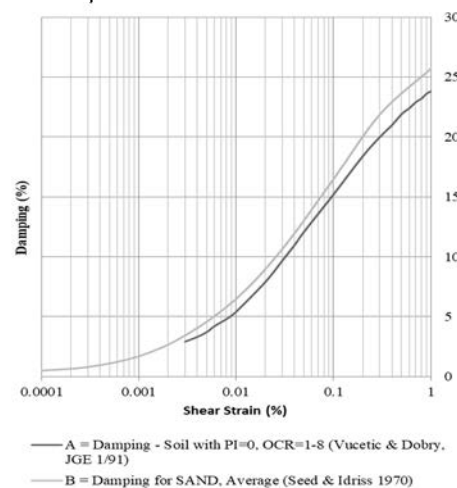


Figure 4: Damping Curves Tailings Types A and B (SHAKE 2003)

6 RESULTS

The predicted maximum acceleration at the top of the soil/ tailings column is compared to the peak acceleration of the input motion to determine the amplification ratios for the analysed tailings/soil profiles.

Figure 5 presents the resultant amplification ratios for the studied scenarios. As can be seen, the acceleration amplification ratios range from 0.1 to around 2 and essentially reduce with an increase in the tailings/soil

profile height. Significant differences between the results of the two tailings/soil types (A & B) are not evident.

The variation of amplification ratio with the first natural (i.e. fundamental) frequency of the analysed tailings/soil profiles is plotted in Figure 6. It is observed that an increase in the natural frequency of the tailings/soil profile (i.e. by increase in shear wave velocity or decrease in height) results in an increase in the amplification ratio.

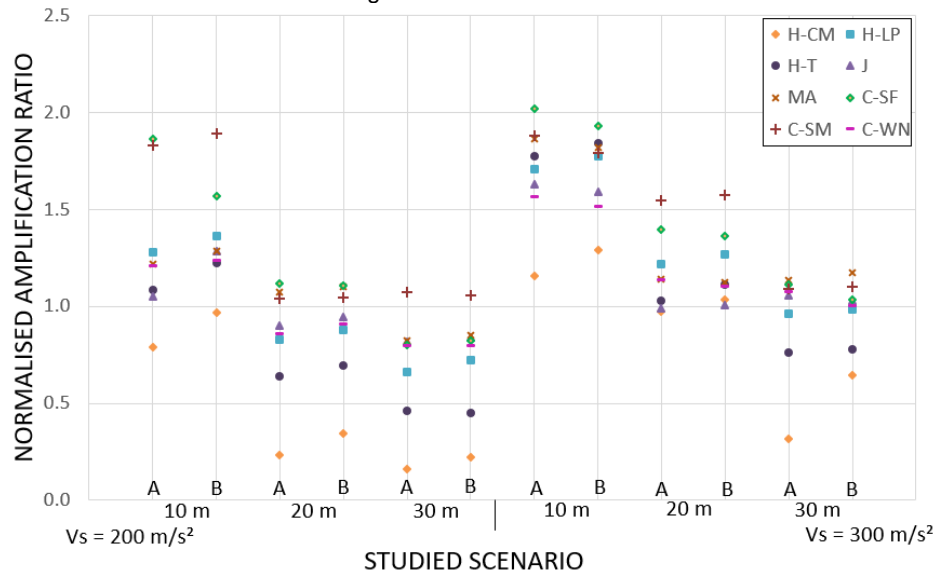


Figure 5: Plot of resulting Normalised amplification ratio per case

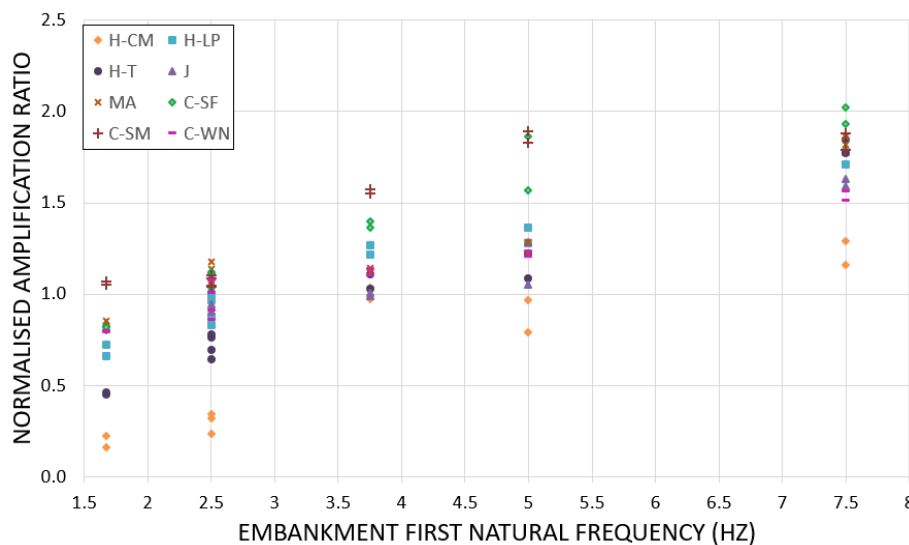


Figure 6: Plot of resulting Normalised amplification ratio per embankment frequency

Reference to Figure 6 indicates that for soil/ tailings profiles with a natural frequency of less than 2.5 Hz the amplification ratio is essentially less than 1. Hence, if no site-specific SHA is available in the early stages of a design study, the PGAs determined from Australian Standards or NSHA seismic hazard maps may be used directly (i.e. amplification ratio of 1) in the stability or liquefaction analyses. For tailings/ soil deposits with natural frequencies of between 2.5 Hz and 4 Hz an amplification ratio of 1.5 may be applied to the PGA. A maximum amplification factor of 2 may be adopted for higher natural frequencies.

7 CONCLUSION

Seismic response analyses were carried out for a number of soil/tailings profiles using SHAKE with the results presented and discussed in the preceding sections. For low to significant consequence category embankment dams or soil/tailings profiles where a site-specific SHA is not available the estimated PGAs from the Australian Standards or NSHA maps may be adopted in the stability and liquefaction assessments without any factoring, if the calculated first natural frequency of the structure is less than 2.5 Hz. This approach may be also applied to embankments and/or soil/tailings profiles during early stages of design. For

high and extreme consequence category tailings or water retaining structures or for sites located regions of high seismicity a site-specific SHA is recommended at the outset.

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